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NORMAL STANDARDS OF THE SPHYGMOGRAM AND THE PULSE WAVE VELOCITY IN PERIPHERAL BLOOD VESSELS **/47

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The authors present data on the normal standards of the pulse wave and the velocity of its spread in vessels of the extremity. These data are necessary for an objective assessment of disturbances of peripheral circulation. The amplitude of the pulse curve, as well as the pulse wave velocity spread are variable for different vascular areas of extremities. An explanation is presented of the relative increase of the volumetric sphygmogram recorded at the upper level of the shin.

Author

The arterial pulse is widely used today in studying diseases of the peripheral vessels. A convenient version of the sphygmograph, using an electric capsule to register small pressure fluctuations, has been proposed by Ye.B. Babskiy and associates (Bibl.1).

The capsule for recording small fluctuations of pressure consists of a Marey drum, where the stylus is replaced by a steel plate of 0.1 mm thickness with wire tensometers connected to it over a differential bridge circuit. The fluctuations of the arterial wall are sensed by a conventional pneumatic cuff of 10 cm width, connected with the Marey drum by an air coupling. The cuff is placed on the part of the extremity to be studied, and a positive pressure of

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** Numbers in the margin indicate pagination in the original foreign text.

40 cm water column is established and checked by a manometer.

The changes in volume on passage of a pulse wave across the part of the /48 extremity being examined cause a proportional rise in pressure in the cuff-capsule system and modify the curvature of the steel plate. As a result the bridge goes out of balance. Since its arms are sensors, an electric signal arises in its measuring diagonal. This signal, in form and amplitude, corresponds exactly to the mechanical processes taking place in the part of the extremity being examined. After amplification, the electric signal is recorded on a loop oscillograph. The resultant pulse curve is a volume sphygmogram. It is a substantial advantage of this method over the pellet method in that the pulse fluctuations can be recorded on any part of the extremity.

Numerous papers were published on the clinical use of the volume sphygmograph (Bibl.3, 4, 10). Insufficient study, however, has been devoted to the normal standards for pulse curves recorded by this method.

We made a sphygmographic study of 30 apparently healthy test subjects, aged 20 to 30 years. The subject was placed on a couch, and after a five minute rest sphygmograms were successively recorded at four levels: at the upper extremities: shoulders, upper and lower third of the forearms, and wrists; at the lower extremities: thighs, upper and lower third of the tibia, and feet. Thus, in each case we recorded 16 sphygmograms, synchronously with, on the same strip, an electrocardiogram. We studied the amplitude variations in the anacrotic rise and the velocity of the pulse wave in various parts of the extremities.

The height of the pulse wave, expressed in some absolute unit, showed considerable individual variation in the various subjects. With this in mind, we made a relative amplitude analysis of the sphygmograms taken from various parts of the extremities. For this purpose, the amplitude of the pulse wave on the shoulder and thigh of each subject was taken as 100, and the amplitude of the other parts of the extremity was expressed in percent of that value (Table 1).

TABLE 1

MEAN VALUES OF AMPLITUDE OF ANACROTIC RISE IN VARIOUS PARTS OF THE EXTREMITIES (IN RELATIVE UNITS)

Site of Test	Amplitude of Anacrotic Rise in Percent of its Value on Thigh and Shoulder	
	Right Limb, M ± m*	Left Limb M ± m
Thigh	100	100
Tibia (upper third)	134.4 ± 4.5	133.1 ± 3.5
Tibia (lower third)	65.7 ± 4.1	65.2 ± 3.4
Foot	46.5 ± 2.9	46.0 ± 3.0
Shoulder	100	100
Forearm (upper third)	132.2 ± 3.9	131.4 ± 3.2
Forearm (lower third)	65.0 ± 3.7	63.7 ± 2.5
Wrist	141.7 ± 6.1	118.4 ± 6.0

* M - Arithmetic mean; m - Mean-square error of arithmetic mean

Table 1 shows that the amplitude of the pulse wave on the lower extremities depends on the region in which it is taken (see also Fig.1). Thus, the amplitude of the anacrotus, taken at the level of the upper third of the tibia, is on the average 33 - 35% greater than on the thigh. On the lower third of the tibia, the amplitude of the pulse curve is about 34 - 35% lower than at the height of the thigh. On the feet, the amplitude of the pulse wave is still lower. A more differentiated study of the extremities, i.e., a recording of /49 sphygmograms from more than four parts of the leg (usually from seven parts) shows that the relative increase in anacrotic amplitude begins at the region of the popliteal space, and that of relative decline at about the middle of the tibia.

The curve (Fig.1) characterizing the variation in anacrotic amplitude with the site of the sphygmogram on the limbs will be called here the amplitude gradient of the pulse. A study of the amplitude gradient of the pulse on the pelvic limb is of great practical importance in the examination of patients with incipient forms of vascular disease, when ordinary analysis of the pulse curve reveals no disorder whatever. One of the first objective signs of disorder in such cases usually is the disturbance of the amplitude gradient (see Fig.1).

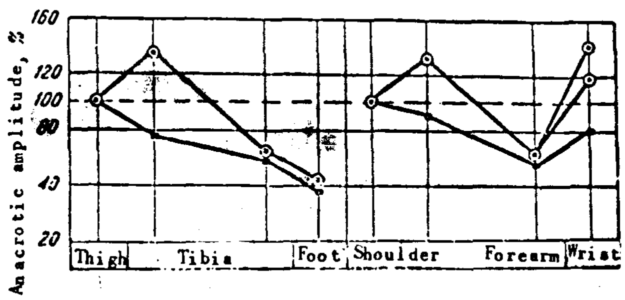

Fig.1 Amplitude Gradients of Pulse on the Extremities
Lines with circles: amplitude variations of sphygmogram on the limbs of healthy subjects (mean data for both limbs); lines with dots: amplitude gradients in patients with endarteritis obliterans

The relative increase in anacrotic amplitude on the upper third of the tibia by comparison with the other parts of the lower limb had been noted by E.L.Romel' (Bibl.3) and, in his opinion, is explained by the more superficial location of the blood vessels in this part of the shin. We also consider that this amplitude feature is connected with the anatomy of the blood vessels of the foot, in particular with the branches of the popliteal artery in the region of the popliteal space on the anterior and posterior great femoral artery. In each of these two arteries, the cross section is only a little smaller than in the unbranched part. For this reason, their total cross section is greater than in the popliteal artery, so that the volume changes in the limb in this region, which take place on passage of the pulse wave, will likewise be greater. As a result, an oscillation of higher amplitude is registered on the volume sphygmogram. We note, in agreement with N.N.Savitskiy (Bibl.4) that the amplitude of the volume sphygmogram at a sufficient cuff width, gives readings that are strictly proportional to the volume changes of the arteries.

The data obtained by a time analysis of the anacrotic part of the sphygmogram (Table 2) provides a certain confirmation of this explanation.

TABLE 2

MEAN DURATION OF ANACROTIC RISE ON SPHYGMOGRAMS OF THE PELVIC LIMB (IN SECONDS)

	Thigh	Tibia (Upper Third)	Tibia (Lower Third)	Foot
	M ± m	M ± m	M ± m	M ± m
Right lower limb	0.171 ± 0.004	0.181 ± 0.003	0.150 ± 0.003	0.147 ± 0.004
Left lower limb	0.173 ± 0.003	0.182 ± 0.003	0.147 ± 0.003	0.144 ± 0.004

As shown in Table 2, the duration of the anacrotic rise on the sphygmograms, taken from various regions of the legs, varies by approximately the same law as the amplitude gradient. According to literature data (Bibl.7, 8, 14), the time of rise of the arterial pulse is directly related to the arterial pressure. However, the arterial pressure in the limbs is a variable quantity, which depends on the site of measurement (Bibl.11) in about the same way as the amplitude gradient and time gradient of the pulse. This fact is probably connected with the sudden surges with which the pressure in any hydraulic system varies over regions with varying cross section and, in particular, increases at places of branching of the system. Thus, there is reason to believe that the /50 variation in the duration of the anacrotic rise on the pulse curve is correlated with the cross section of the peripheral blood vessels.

The interference of the pulse waves described by Wiggers (Bibl.6) may also play a certain part in the causative effect for the nonuniformity of the amplitudes of the sphygmograms on various parts of the lower limb.

The amplitude gradient of the pulse on the upper limbs differs somewhat from the gradient on the lower limbs. These differences are primarily related to the second increase in the amplitude of the anacrotic rise of the wrists (see Table 1 and Fig.1). This continuation of the amplitude gradient on the upper limbs probably is also due to the anatomy of the arterial system.

The next feature of the amplitude gradient of the pulse in the upper limbs is the pronounced asymmetry of the pulse waves on the right and left wrists. In the 27 test subjects, the absolute amplitude (i.e., expressed in mm of deflection of the trace) of the pulse wave is greater on the right wrist than on the left. In only three of the subjects was the opposite relationship noted. The asymmetry in most cases was extremely marked: Whereas, in the other regions of the extremities, the ratio of the right-limb amplitudes to those on the symmetrically corresponding region of the left limb fluctuated as a rule within ±20%, these same ratios on the wrists ranged from -30 to +100%. The pronounced asymmetry of the amplitude of the pulse waves on the wrists in healthy subjects is most likely due in part to the better development of the musculature of the right hand and the greater blood supply to it.

According to literature data (Bibl.2, 5, etc.), the asymmetry of the arterial vibrations is regarded as having a certain diagnostic significance. Our own data indicate that this test should be used with caution. In particular, inequality of the amplitudes of the pulse waves on symmetric regions of the limb of up to 20% (except for the wrist) may be encountered in apparently healthy subjects with no vascular or nervous disease whatever.

The amplitude gradient of the pulse on the upper limbs is likewise of great practical significance for the diagnosis of disorders in peripheral circulation (see Fig.1).

The normal standards of variation in the pulse wave amplitude established by us, on comparison with the data obtained by examination of various patients, give information not only on the disturbance of circulation in the peripheral blood vessels but also on the degree and severity of the disorder.

In spite of the considerable number of reports on studies of the pulse wave velocity in normal and pathological cases, the value of this index in various regions of the limbs has never been sufficiently defined. Still, this is a rather important factor, since it is well known (Bibl.4) that this ve- /51 locity is a variable quantity and sometimes changes abruptly over short distances. The volume sphygmograph is the most convenient method of investigating this point.

We determined the rate of propagation of the pulse wave in the following manner: The cuff was successively applied to the proximal and then to the distal end of the region of the limb under study. Each time an ECG was taken simultaneously with the sphygmogram. We then calculated the time between the top of the peak R of the ECG and the beginning of the anacrotus on the curves recorded in the proximal (Tp) and the distal end of the region of the study (Td) and measured the length of the region (L).

The velocity of the pulse wave (V) was calculated from the formula

$$V = \frac{L}{T_d - T_n} \text{ m/sec.}$$

In the test subjects, we determined the pulse wave velocity in the following regions of the limbs: thigh to upper third of tibia, upper third of tibia to lower third; lower third of tibia to foot; then, shoulder to upper third of forearm; upper third of forearm to lower third; lower third of forearm to wrist. We also determined the mean velocity on the limb as a whole, as well as the rate of propagation of the pulse wave in the aorta.

This velocity was calculated from the formula:

$$V = \frac{L_a}{Tf - tt} \text{ m/sec},$$

where L_a is the length of the blood vessels from the heart to the thigh; T_f is the time between the peak Q of the ECG and the beginning of the anacrotus on the femoral pulse; and t_t is the stress time of the ventricles of the heart (determined from the cardiodynamogram).

TABLE 3

RATE OF PROPAGATION OF PULSE WAVE IN VARIOUS ARTERIES

Regions in which the Rate of Propagation of the Pulse Wave was Determined	Mean Value of V, m/sec	Extreme Range of Fluctuation of V, m/sec
Aorta	4.8	4 - 7
Upper limb as a whole	7.3	5 - 9
Shoulder to forearm (upper third)	6.2	4 - 11
Upper to lower third of forearm	13.1	10 - 17
Forearm (lower third) to wrist	8.0	6 - 10
Lower limb as a whole	9.5	8 - 11
Thigh to tibia (upper third)	14.0	12 - 16
Upper to lower third of tibia	7.1	6 - 8
Tibia (lower third) to foot	13.2	9 - 20

The resultant data (Table 3) are in satisfactory agreement with literature concepts to the effect that the rate of propagation of the pulse wave is relatively greater in arteries of the muscular or distributing type (in the limbs) than in arteries of the elastic or conducting type (in the aorta).

We are also able to confirm reports by Soma and Staehelin (Bibl.12, 13, etc.) that the mean pulse wave velocity is higher in the lower limbs than in the upper. This difference amounts on the average to 130%, and ranges from 110 to 150%.

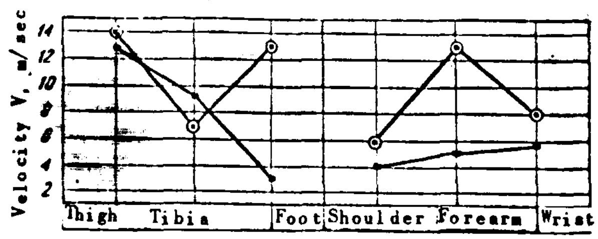

Fig.2 Rate of Propagation of Pulse Wave in Various Parts of the Limbs
Lines with circles: variations of velocity in the limbs of healthy subjects; lines with dots: in the limbs of patients with endarteritis obliterans

According to Gauer (Bibl.9), the velocity of the pulse wave in the blood vessels of the lower limb is practically constant over its entire length. According to our data as well (Fig.2), the pulse wave velocity is sharply higher in the proximal part of the lower limb than it is in the aorta, but then it /52
regularly declines in the tibia in all test subjects. On the distal division of the lower limb as well, we noted a regular rise in the pulse wave velocity. We also confirmed the data by Hauk who found that, in the wrist, the velocity of the pulse wave is sharply lower than on the forearm.

It follows from these data that the pulse wave in muscular-type arteries passes at variable velocity.

We have not yet found a satisfactory explanation for the observed variation patterns of the pulse wave velocity in the arteries of the limbs, but even today they do have a certain practical value in the examination of patients with vascular disease. For example, in various forms of endarteritis, as a rule, the rate of propagation of the pulse wave declines (see Fig.2). This sign appears as early as the disturbance of the amplitude gradient of the pulse. The conclusion that the velocity of the pulse wave of the patient is relatively decreased (especially in cases of a mild vascular disorder) can be established only by comparison with normal standards. Here, it is not only the absolute values of the velocity that are significant but also the character of the variation of V in various regions of the limbs.

CONCLUSIONS

1. The amplitude of the volume sphygmogram is not the same for different regions of the upper and lower limbs. These variations may be described in the form of our proposed amplitude gradients of the pulse in the extremities.

2. The variations in pulse amplitude are probably connected with the anatomy of the arterial blood vessels in various regions of the limbs.

3. The rate of propagation of the pulse wave in various regions of the limbs is a variable quantity which depends on the site of sphygmometry.

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